TRANSPORATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (University or Contractor):__Kansas DOT_____

INSTRUCTIONS:

Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Project Number **TPF-5(351)**	**Transportation Pooled Fund Program - Report Period:** ☐ Quarter 1 (January 1 – March 31) X Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 4 – December 31)	
Project Title: Self De-Icing LED Signals		
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Lead Agency Project ID: **RE-0721-01**	**Other Project ID (i.e., contract #):**	**Project Start Date:** August 15, 2016
Original Project End Date: **August 2019**	**Current Project End Date:** **June 2021**	**Number of Extensions:** 1

Project schedule status:

☐ On schedule X On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
$240,000 original, $360,000 with addendum	$213,221	71%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$8,163	$8,163	3%

Project Description:

This pooled fund project will develop and demonstrate new self de-icing LED signals for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The self de-icing LED signals will adopt one or both of two novel architectures (Figure 1), including (a) "Heated Lens Lighting Arrangement" that uses a single high-power LED and (b) "Heat Arrangement of LED Arrays in Low Profile" that deploys multiple LEDs. The heat generated by the LED(s) is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions.

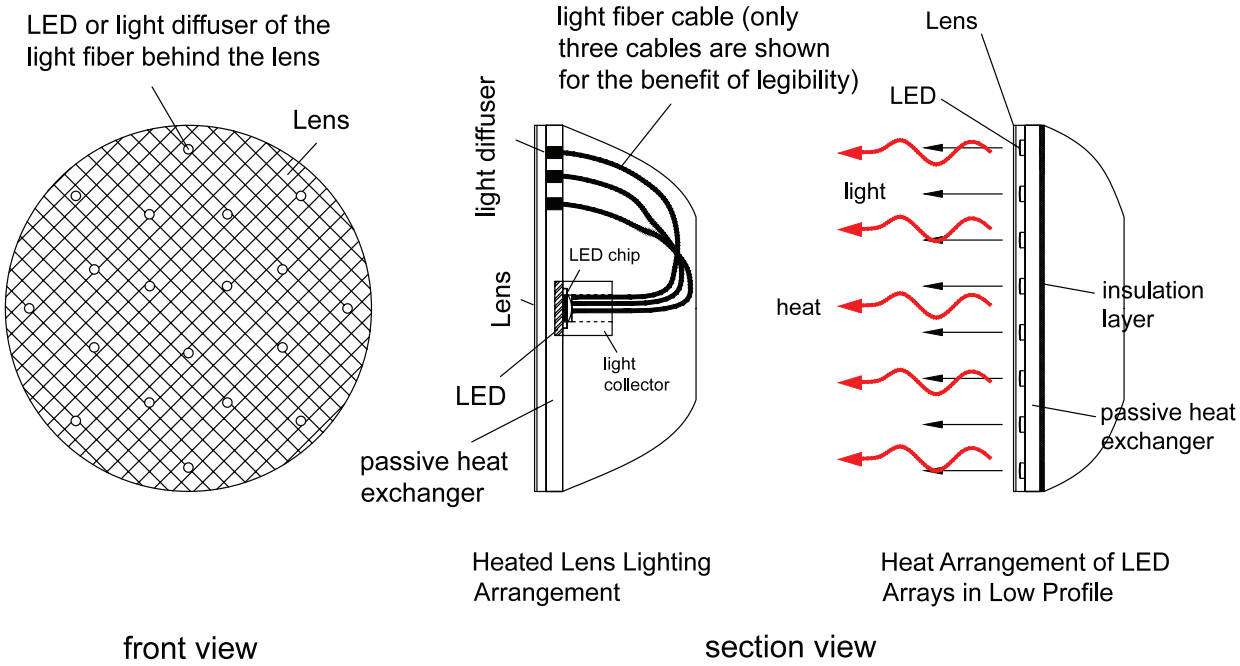


Figure 1 The concept of the self de-icing LED signal light, which adopts new architecture of "Heated Lens Lighting Arrangement" or "Heat Arrangement of LED Arrays in Low Profile"

Fully working prototypes of the self-de-icing LED signals have been developed and tested in the laboratory. They have been tested in closed-course settings on the roof of an engineering building followed by field tests on highway intersection and railroad wayside or at-grade crossing signal lights. Each participating agency is required to provide support of three years of funding ($20,000/year, totaling $60,000) and will be guaranteed a field test site in each state for testing the fully working prototypes catering to their specific needs of the new type of signals. The research team will work with each participating agency to identify the desired test site on highway intersections or rail track sections and the desired technical specifications for testing the prototypes.

The investigative approach for the proposed project is divided into the three stages. Work in Stage 1 focuses on laboratory development and tests. Work in Stage 2 focuses on testing the three prototypes in a closed-course setting on the roof of the University of Kansas engineering complex and powered by the signal controller cabinet. Work in the third and final stage involves field testing of the developed prototypes on identified highway signalized intersections and rail track sections. On-site demonstration of the prototype signals will also be held for project partners and state DOTs to initiate the implementation process. A final report will provide all relevant data and results along with plans for implementation of the self-de-icing LED signals in affected states.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

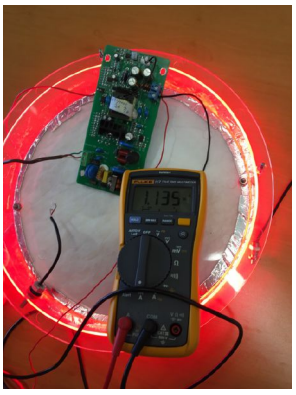
During the second quarter (April 1, 2019 – June 30, 2019) of the project period, we have the following accomplishments.

In the present quarter (April 1, 2019 – June 30, 2019), issues with LED drivers have been resolved with desired changes, and the ambient temperature sensor of the drivers was improved for switching power output at 4°C with acceptable tolerances. A total of six new driver samples of the second generation were made and tested thoroughly in the cold room and on the roof. Based on the test results, improvements have been made for the third generation of LED drivers. Now the company has been making samples of the third generation of the new LED drivers for our follow up tests. Additional LED driver samples of the third generation were ordered in large quantity (21) for testing of their field performance for any further improvements in need for control of the yield rate in production.

More details are listed as follows.

We worked with the electronics company of the LED drivers and resolved some issues and problems of the custom-made prototype LED drivers, including:

- Decreased the size of the power connector of the temperature sensor, so the sensor no longer has problem to connect through the inside hole of the installation nut and the opening hole on side of the plastic housing (Figure 1).
- Downsized the length of the ambient temperature sensor to 6 mm (Figure 1)
- Changed the power board switch from double switch to more reliable single switch (Figure 1)
- Enlarged the inside size of the installation hole from original **4.5mm x 3.5mm** (LxW) to **6mm x 4.5 mm** (Figure 1)
- Changed the final designed output current of Yellow/Green LED drivers to **0.40 A (derated) /0.84 A(full output)** (Figure 1)
- Changed the final designed output current of Red LED drivers to **0.60 A (derated) /1.1 A(full output)** (Figure 1)
- Of the new tested TYPE 2 samples (whose switching temp sensor was set by the factory at 6°C), the ambient temperature sensor's switching temperature, based on our laboratory test results, is actually close to approximately 4° C.



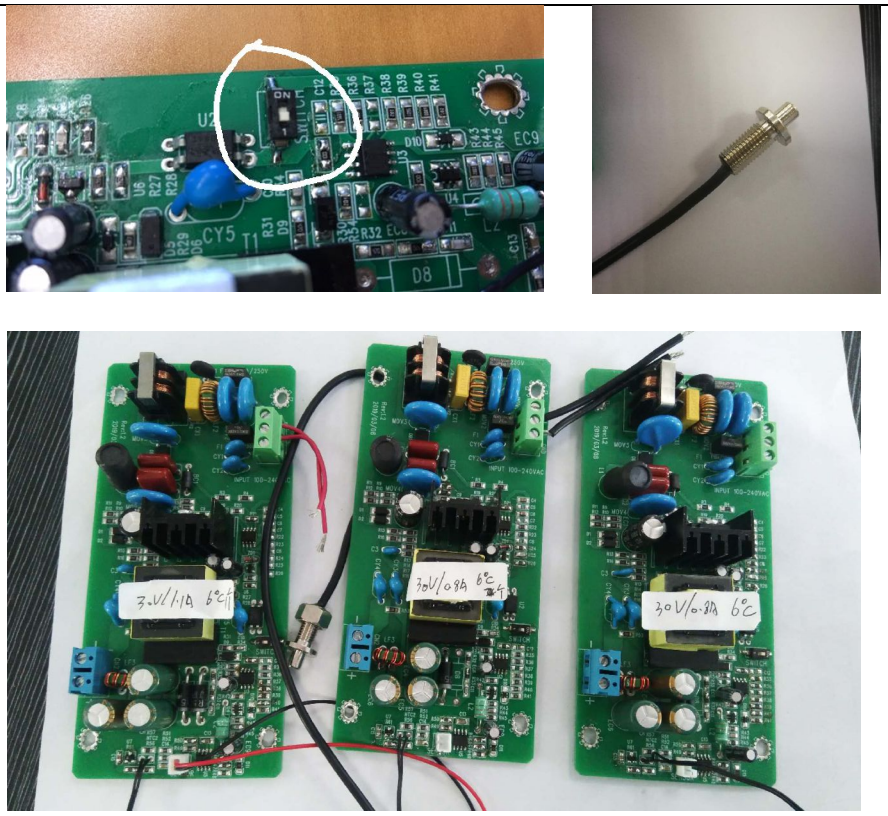


Figure 1 The second generation of LED drivers with all improvements

The revised signal housing of the fourth generation was tested in the lab for quick assembly with the second generation of LED drivers, as shown in Figure 2. Once the new third generation of LED drivers arrived, we will start the full testing of thermal and lighting performance in preparation of the field tests.

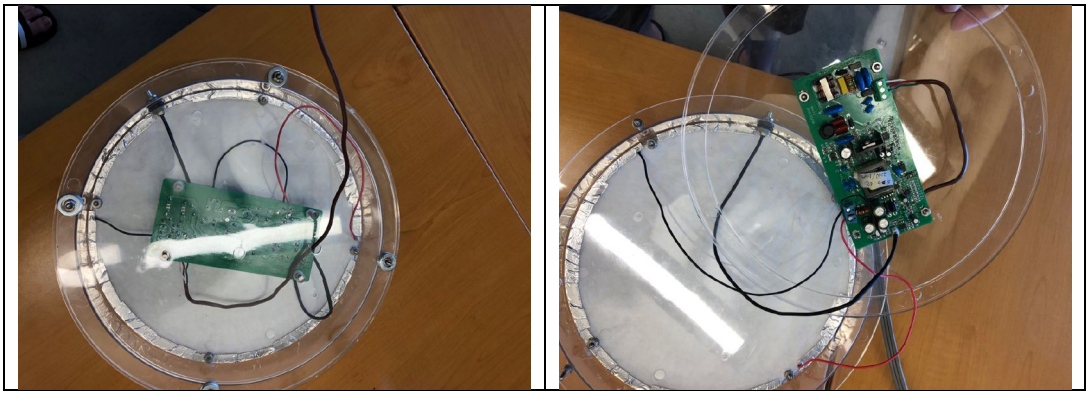


Figure 2 Improved signal housing fitted with the second generation of LED drivers.

Moreover, in the present quarter, the fully functional prototypes were continuously under test on the roof of an engineering building and powered by a traffic control cabinet for closed-course performance and reliability tests.

Another manufacturer for Fresnel lenses was contracted for lower unit price with high quality control. Samples of the new Fresnel lenses were ordered and tested in the laboratory with satisfactory results, as shown in Figure 3. Based on the test results, the fresnel lens type #1 (**Model #1511**) was picked for field tests. Additional 5000 pieces of the new Fresnel lenses (**Model #1511**) were ordered and arrived in preparation for upcoming field tests.

signal light color	red	D15-F11.5				
tilting angle counted from 70 deg	Illuminance in lux			Average (lx)	distance(m)	intensity (cd)
0	204.3	204.4	205	204.6	2.236	1022.8
0.5	207.1	207	206.6	206.9	2.236	1034.4
1	207.3	207.3	207.1	207.2	2.236	1036.1
1.5	206.3	206.3	206.4	206.3	2.236	1031.6
2	205	205.1	204.9	205.0	2.236	1024.9
2.5	202.8	202.8	202.8	202.8	2.236	1013.9
3	199.9	200	199.8	199.9	2.236	999.4
3.5	196.7	196.8	196.7	196.7	2.236	983.6
4	193.3	193.4	193.4	193.4	2.236	966.8
4.5	189.8	189.8	189.9	189.8	2.236	949.1
5	187.1	187.2	187	187.1	2.236	935.4
6	185.4	185.4	185.4	185.4	2.236	926.9
7	179.2	178.9	178.9	179.0	2.236	894.9
8	176.6	176.7	176.4	176.6	2.236	882.8
9	173.1	173.1	173	173.1	2.236	865.3
10	169.9	170	170	170.0	2.236	849.8
20	149.1	148.8	148.8	148.9	2.236	744.5
30	20.62	20.66	20.64	20.6	2.236	103.2
40	14.31	14.31	14.31	14.3	2.236	71.5
50	11.91	11.93	11.92	11.9	2.236	59.6
60	24.36	24.34	24.31	24.3	2.236	121.7
70	9.69	9.7	9.68	9.7	2.236	48.4

Peak minimum maintained luminous intensity values, at θ_{Vert} = –2.5 deg and θ_{Horiz} = 0 deg [$\mathbf{I}_{(-2.5,\,0)}$], by size and color of the module are:

Color	$\mathbf{I}_{(-2.5,\,0)}$ 200mm	300mm
Red	165 cd	365 cd
Yellow	410 cd	910 cd
Green	215 cd	475 cd

(a) Lighting performance of Fresnel lens type #1 (**Model #1511**): focus length 11.5 mm; Thickness 1.5 mm + / - 0.2 mm; Diameter 15 mm, with tolerance of 0.1 mm (approximately 14.9 – 15.1 mm)

signal light color	Red	D15-F15				
tilting angle counted from 70 deg	Illuminance in lux			average (lx)	distance(m)	intensity (cd)
0	145.1	144.9	144.8	144.9	2.236	724.6
0.5	144	143.8	143.7	143.8	2.236	719.1
1	142.6	142.7	142.5	142.6	2.236	713.0
1.5	142	142	141.9	142.0	2.236	709.8
2	140.7	140.7	140.8	140.7	2.236	703.6
2.5	139.8	139.8	139.7	139.8	2.236	698.8
3	139.3	139.2	139.1	139.2	2.236	696.0
3.5	138.4	138.5	138.3	138.4	2.236	692.0
4	137.6	137.6	137.5	137.6	2.236	687.8
4.5	136.5	136.3	136.4	136.4	2.236	682.0
5	135.8	135.8	135.6	135.7	2.236	678.6
6	134.5	134.3	134.3	134.4	2.236	671.8
7	132.7	132.8	132.7	132.7	2.236	663.6
8	131	130.9	130.8	130.9	2.236	654.5
9	129.8	129.7	129.8	129.8	2.236	648.8
10	128.6	128.8	128.8	128.7	2.236	643.6
20	119.2	119.1	119.1	119.1	2.236	595.6
30	32.1	32	32	32.0	2.236	160.2
40	15.7	15.72	15.69	15.7	2.236	78.5
50	13.39	13.39	13.38	13.4	2.236	66.9
60	27.25	27.24	27.24	27.2	2.236	136.2
70	10.11	10.12	10.11	10.1	2.236	50.6

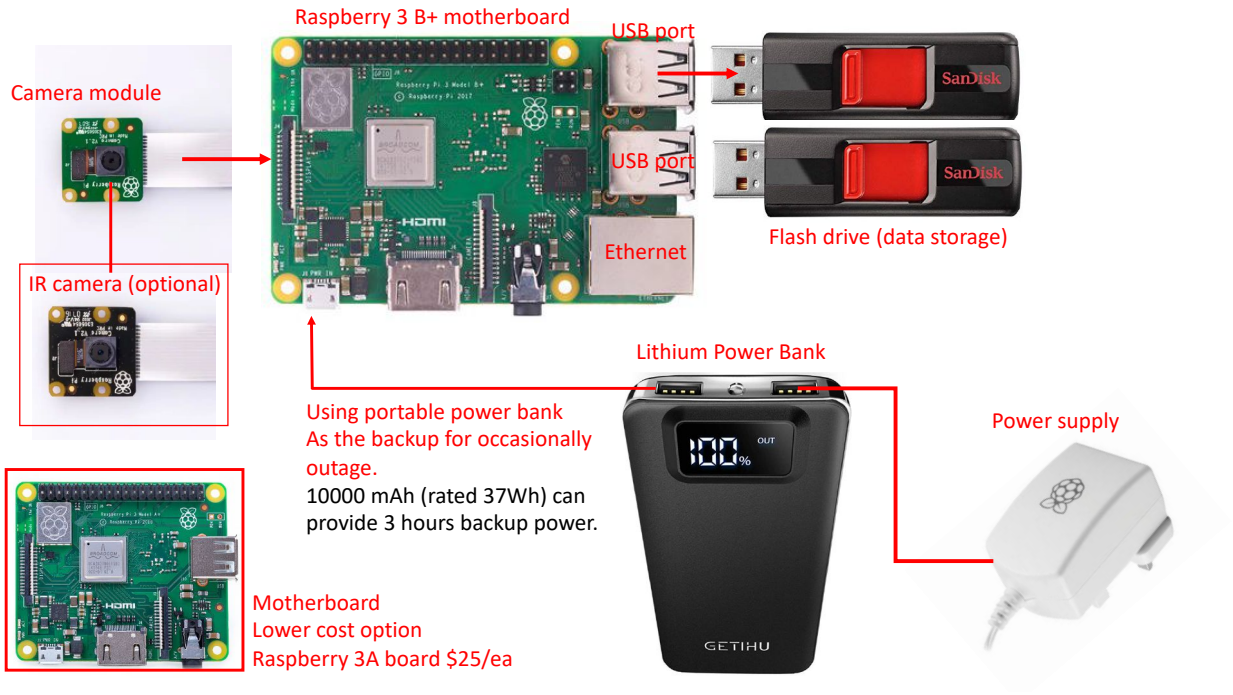
Peak minimum maintained luminous intensity values, at θ_{Vert} = –2.5 deg and θ_{Horiz} = 0 deg [$\mathbf{I}_{(-2.5,\,0)}$], by size and color of the module are:

Color	$\mathbf{I}_{(-2.5,\,0)}$ 200mm	300mm
Red	165 cd	365 cd
Yellow	410 cd	910 cd
Green	215 cd	475 cd

(b) Lighting performance of Fresnel lens type #2: focus length 15.0 mm; Thickness 1.7 mm + / - 0.2 mm; Diameter 15 mm, with tolerance of 0.1 mm (approximately 14.9 – 15.1 mm)

Figure 3 Improved signal housing fitted with the second generation of LED drivers.

Moreover, monitoring cameras – Raspberry 3 B+ motherboard and accessories – have been designed and are currently being custom built in house, as shown in Figure 4, which will be mounted at each field test site for year-around real-time monitoring and data recording of the new signals to be tested in the field.



The camera is being tested in the lab

Figure 4 Custom design and lab testing of the monitoring cameras – Raspberry 3 B+ motherboard and accessories, to be used in field tests over 1-2 years without interruption.

Last but not the least, with additional committed pooled fund of $120,000 from New Jersey ($20,000 in Year 2), Wisconsin ($40,000 in Years 2 and 3), and Maryland ($60,000 in Years 2, 3 and 4), the research team

is proposing and already got approval on extended field work. As shown in Table 1, in addition to original 3 field test sites in California, Kansas, and Michigan, the scope of extra work includes research & development (R&D) of three more fully working prototypes of the self de-icing LED signal lights and their validation using three new/updated field tests in Wisconsin, Maryland, and in a third test site close to New Jersey and Pennsylvania.

Table 1 A total of six field test sites and the number of prototype self de-icing LED signals to be developed and tested in the field with the extended budget of $360,000. The states providing additional funding of $120,000 are highlighted in Yellow.

Participating Agencies	Year 1	Year 2	Year 3	Year 4	Number of Test Site	Number of Prototypes
California	$20,000	$20,000	$20,000		**1**	3 (R, G, Y) or as needed
Kansas	$20,000	$20,000	$20,000		**1**	3 or as needed
Michigan	$20,000	$20,000	$20,000		**1**	3 or as needed
Wisconsin	$20,000	$20,000	$20,000		**1**	3 or as needed
Maryland	-	$20,000	$20,000	$20,000	**1**	3 or as needed
New Jersey	$20,000	$20,000	-		**1**	3 or as needed
Pennsylvania	-	$20,000	-			

Accordingly, preparations are in progress for field tests. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) are participating in field testing and evaluation of the prototypes.

Anticipated work next quarter:

Starting from July 1, 2019 till Sept. 30, 2019, we are planning to conduct the following tasks.

1. Test and validate the improved third generation LED drivers, in qty of 21, to be used for final field tests.
2. Identify field test sites and test specifications at each site with the aid of sponsor states.
3. Assemble all improved prototypes to be tested in the field sites.
4. Travel to the field for field installation and field test.
5. Continue roof testing of the improved prototypes in the closed-setting for continuous improvements.

Significant Results:

As of June 30, 2019, we have achieved the following significant results.

- This project was launched in Aug 2016 with six participating states (Kansas, California, Michigan, New

Jersey, Wisconsin, and Pennsylvania) and an initial budget of $240,000. Maryland is expected to officially join the study by the end of this year with additional contribution of three years funding.

- An expert panel meeting was held in early March. Discussions were held on desired specifications of the prototype signals and possible field test sites as well as the field evaluation of the prototypes.

- Necessary equipment, components and insulation materials are being procured to develop and build the fully working prototypes of the finalized design and test for their thermal and lighting performance. We will continue to order LED drivers, electricity monitors, waterproof security video cameras, other mounting accessories and materials, etc., for monitoring the performance of the prototypes in the field tests in the upcoming winter season.

- Appropriate color LED modules, which are not available in the market, were designed in-house and custom-made with the aid of the industrial partner.

- Three preliminary prototype signals (Red, Yellow, and Green) of Type 1 have been developed in house, each deploying 26 custom-made color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". They are under laboratory testing for improvements.

- Tested the lighting and thermal performance of the preliminary prototypes of the Type 1 signal lights (Figure 1). Based on the test results, new design with a lot of changes and improvements has been finalized for final products.

- Finalized the design of Type 1 self de-icing LED signals using 96 custom-made mediate-power color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile". Designed in house and custom-made our own color LED modules (for each color R, G, Y) for making the fully working prototype signals of the first type with the aid of our industrial partner.

- Worked with the factories to optimize the mounting method of the custom-made LED modules on the 3-5 mm thick aluminum MPCB back plate serving as the passive heat exchangers of aluminum alloy for assembly.

- Custom-made three prototypes of the LED signals of Type 1 using 96 custom-made mediate-power color LEDs mounted in an array via "Heat Arrangement of LED Arrays in Low Profile", with regular paint coating, and finished laboratory testing for improvements and optimizations to finalize the design.

- Improved and custom-made three new signal light engines using 96 medium-power LEDs (0.25 Watt each) mounted in an array via "Heat Arrangement of LED Arrays in Low Profile" but with Tin coating (Figure 3) and tested them to improve the heating performance (to make faster heat transfer).

- Finalized the design of the signal lens that adopts a whole piece design with smooth and flat outside surface and integrated with 96 additional custom-made Fresnel lenses sitting inside the signal lens over each LED on the inside surface to focus the light serving as a collimator lens. Based on the testing results, the signal light engines with TIN coating may have superior thermal performance, however, further testing in the laboratory and field is necessary to validate the final choice.

- Identified and started custom-making the Fresnel Lens from HongXuan Optoelectronic company with

diameter 15 mm and focal length 6 mm (model # HX-F015006).

- Developed the new whole-piece signal housing, new Fresnel lenses, LED drivers, and other accessories for the Type 1 self de-icing LED signal lights, with the aid of the industrial partner.

- Found and selected a qualified plastic molding company to custom make the three parts of the plastic housing of fully working prototypes of Type 1 signals that deploy 96 mediate-power LEDs via the architecture of "Heat Arrangement of LED Arrays in Low Profile". The new housing will be used for the new LED signal lights.

- The non-provisional patent application for the invention of Type 2 self de-icing signal light was officially approved by the USPTO and issued on Dec 26, 2017, patent No. US 9,851,086 B2.

- Started custom-making and modeling of the signal housing. Three samples were delivered for examinations and laboratory tests for necessary calibrations and further improvements.

- Started custom-making the LED drivers with desired specifications based on our test results. Seven LED drivers were delivered for sample testing.

- The custom-made signal housing is ready for production of products with possible minor adjustments for field tests in different states. Six improved samples have been delivered and thoroughly tested in laboratory and closed-setting tests on the roof.

- New type of screws for uses in the signal housing are self-designed and will be custom-made with Fastenal company.

- A company is custom making two improved and finalized types of LED driver, one for YELLOW and GREEN signal lights (output 0.8 A, maximum 30 Watts), the other for RED signal light (output 1.1 A, maximum 30 Watts). The new LED drivers have temperature Sensor control, when the temperature is above 4 degree Celsius, the LED driver output will be derated (For Yellow + Green LED lights, output current 0.5 A, approximately 17- 18 Watts; For Red LED light, output current min 0.6 A, approximately 15-16 Watts.) When the temperature sensor is turned off or failed for any reasons, the power output will be restored to 100% as default.

- The self-deicing signal lights have higher light output than the codes and standards required in all viewing angles from 0 deg to 70 deg as measured, even at the derated power output.

- We have been conducting a closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building, in preparation for field tests.

- Seven states have officially participated in this project, including Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania and Maryland to provide support.

- A project addendum is proposed to conduct two additional field tests, one in Wisconsin and another one in a test site among Maryland, Pennsylvania, and New Jersey. A budget of $80,000 for the addendum is proposed to be spent starting on 5/18/2018 until the end of the project

- We have been continuously testing the closed-course performance and reliability of the prototypes previously mounted on the roof of M2SEC building. All signal lights were powered by the signal controller cabinet with real signaling time cycles (in a cycle length of 90 seconds, Red signal light ON for 50 seconds, Green signal light ON for 35 seconds, and Yellow signal light ON for 5 seconds. The temperature data were recorded every 10 seconds continuously over the entire test period, which will be continuously conducted over both winter and summer seasons in 2019.

- We have designed and custom made new types of screws to improve the connection strength of the screws integrated with the plastic housing. This type of screws are finalized products to be used in all finalized plastic housing.

- We have designed and custom made two types of LED drivers, including one type of custom-made LED driver for **red signal light** (input: 100-240 VAC, output: 0.6-1.1 A, max 30 W), and a second type custom made LED driver for **green/yellow signal light** (input: 100-240 VAC, output: 0.5-0.8 A, max 30 W). Both types of LED drivers are now integrated with a remote temperature sensor for controlling the power output in light of the ambient air temperature. An on/off switch is designed for temperature controls in winter and summer modes which could override the operation of the temperature sensor.

- We have accordingly improved and finalized the plastic housing of the fully working prototype signals of Type 1 with changes/improvements listed below, with assist of the plastic molding company — Eco Molding. Eco Molding company has custom made seven samples of the finalized new plastic housing for validations tests before actual product production.

- We have produced 60 pcs of the finalized LED engines with the aid of the industrial partner, ready for the upcoming field tests.

- We have also updated and custom made 60 pcs of glass disc which have four small mounting holes removed on the edge (the original glass disc had 8 mounting holes).

- We also custom made plastic mounting bars for mounting the glass disc to the LED light engine.

- We are working on getting improvement on custom-made Fresnal lens model number HX-F0150115 (diameter 15 mm, thickness 2.0 mm, focal length 11.5 mm) to increase tolerance of the thickness (approximately 1.8 – 2.1 mm) while reducing the unit cost.

- We are in preparation for field tests. Three fully functional prototypes of the fourth generation were mounted on a signal pole on the roof of an engineering building, powered by a traffic control cabinet for closed-course performance and reliability tests.

- Three more fully functional prototypes of the fourth generation were also tested in a well-controlled cold room for the performance of the ambient temperature sensor connected to the LED driver for switching full/derated power output. Based on the test results, we are adjusting the power output of the LED drivers. We are also making minor adjustments of the signal housing for quick assembly of the real products. Results have been used to evaluate the readiness of the prototypes for field tests starting in next quarter.

- Corrected some problems and resolved issues of the custom-made LED drivers, including (1) decreased

the size of the power connector of the temperature sensor, (2) decreased the length to 6 mm, (3) changed to more reliable single switch, (4) enlarged the inside size of the installation hole to 6mm x 4.5 mm, (5) changed the final designed output current of Yellow/Green LED drivers to 0.40 A (derated) /0.84 A(full output), (6) changed the final designed output current of Red LED drivers to 0.60 A (derated) /1.1 A(full output), (7) improvements on temperature measurement accuracy, redesigned logic circuits, and changes of electronic parts used on the LED PCB boards.

- The signal housing of the fourth generation LED signal lights was revised for quick assembly. We have received the new prototypes of the housing with desired changes, which were tested in the laboratory with satisfactory performance.

- Other parts like glass mounting discs have also been improved in house for enlarging the installation holes to fit the new housing.

- Additional vendors for Fresnel lenses were contacted for lower unit price with higher quality control than the current lens vendor. Based on the lab test results, a total of 5000 PCS of new Fresnel lenses (**Model #1511**) were ordered from the new vendor for field tests.

- Based on the lab test results on the second generation of LED drivers, a total of 21 pcs of the third generation of LED drivers were ordered for lab tests, in preparation for the field tests.

- Monitoring cameras – Raspberry 3 B+ motherboard and accessories – have been designed and are currently being custom built in house, which will be mounted at each field test site for year-around real-time monitoring and data recording of the new signals to be tested in the field.

- A new proposal was approved on extended work with increased total project cost of $360K and extended new end date of June 30, 2021.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

None.